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TITLE OF INVENTION

METHOD AND SYSTEM FOR DETERMINING A LOCATION OF A WIRELESS TRANSMITTING DEVICE AND GUIDING THE SEARCH FOR THE SAME

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METHOD AND SYSTEM FOR DETERMINING A LOCATION OF A WIRELESS TRANSMITTING DEVICE AND GUIDING THE SEARCH FOR THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from and is related to the following prior application: “Method and System for Determining a Location of a Wireless Transmitting Device and Guiding the Search for the Same”, United States Provisional Application Number 60/401240, filed August 06, 2002.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable.

REFERENCE TO SEQUENCE LISTING, A TABLE, OR A COMPUTER PROGRAM LISTING

[0003] Not Applicable.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0004] This invention relates generally to wireless systems and, in particular, to determining the location of a wireless transmitting device, and to guiding the search for said wireless transmitting device.

DESCRIPTION OF THE RELATED ART

[0005] Wireless devices include cellular, PCS (Personal Communication Systems), cordless and satellite phones, wireless PDAs (Personal Digital Assistants) and laptop computers, two-way pagers, radio tags, etc. Collectively these are referred to herein as "wireless devices".

[0006] The need for locating, tracking and searching for wireless devices is increasing. Applications include:

[0007] Emergency Response:

[0008] A notable emergency response service is the enhanced 911 (E911) service mandated by the FCC (Federal Communications Commission) for all cellular licensees, broadband Personal Communications Service (PCS) licensees, and certain Specialized Mobile Radio (SMR) licensees in the United States. E911 service is to provide the operators at the PSAP (Public Safety Answering Point) with information such as calling number, location of serving base station, and caller's Automatic Location Identification (ALI) in longitude and latitude. This automatic information enables the PSAP operators to dispatch emergency response teams for wireless 911 callers in the similar fashion as for the wire line 911 callers. The location accuracy and reliability required by FCC have been revised several times since their first release, compromising what is needed and what is possible. At the time of this invention, the requirements are

- For handset-based solutions: 50 meters for 67 percent of calls, 150 meters for 95 percent of calls;
- For network-based solutions: 100 meters for 67 percent of calls, 300 meters for 95 percent of calls.

[0009] Pursuit of Criminals:

[0010] To allow law enforcement agencies to track and locate wanted criminals who use wireless devices; to allow the public to report information about offensive callers' identification and location.

[0011] Tracking of Fraudulent Calls:

[0012] Cellular telephone fraud causes huge revenue losses to the service providers. Real-time location of fraudulent calls will help stop the spread use of "cloned" phones.

[0013] Recovery of Stolen Vehicles and Valuable Goods:

[0014] Wireless devices attached to the protected objects will enable the tracking and recovery thereof.

[0015] Target Monitoring and Searching:

[0016] Wireless devices attached to the targets can enable the monitoring and searching of such targets, as children, patients, herds, parolees and probationers, controlled materials and equipment, or toxic waste containers.

[0017] Depending on the application, wireless location systems face various technological challenges. Achieving high location accuracy anywhere, anytime, under diversified terrain conditions, and at a low cost is a challenge common to many location applications. Particularly for conventional E911 technologies, the prior art solutions are divided into two major categories: network based and handset based. In network based prior art solutions, location accuracy is sensitive to multipath propagation, number of available detection stations, and geographical geometry of the target in relation to the available detection stations. In handset based prior art solutions using GPS, location accuracy is susceptible to blockage in dense urban areas and inside buildings. The handset based prior art solutions also have problems to provide E911 service to legacy devices already in use. To

achieve a required accuracy throughout coverage areas and terrains, the cost is often found far beyond the acceptable limit for operators and many end users. In addition, the prior art E911 solutions do not address the need to guide the search for the target on site.

BRIEF SUMMARY OF THE INVENTION

[0018] A method and a system to locate wireless devices that are transmitting wireless signals (referred to herein as "Target Wireless Transmitting Devices", or "Wireless Transmitting Devices", or "Target Devices", or TD for short), and to guide the search personnel(s) or searching robot(s) to physically reach the wireless transmitting devices are described through preferred embodiments.

[0019] In one aspect of this invention, the method utilizes a system that is composed of one or a plurality of detection stations (DS), at least one of the DSs is carried on board of a moving platform (herein referred to as a Movable Detection Station, or MDS, for short), for examples, on board of a police car, an ambulance, a fire truck, a helicopter, a balloon, an airship, a boat, or the like, or carried in hand or on shoulder by the operator of the MDS. Either operating alone or operating in conjunction with other DS and MDS, a MDS measures the location of the TD while moving en route to or around the TD. The method thereby involves making use of the advantages that are made available by the mobility of the MDS, by the movement of the MDS, and by the close distances of the MDS with respect to the TD.

[0020] In another aspect of this invention, the method utilizes a system that is composed of also one or a plurality of handheld devices, referred to as guiding devices. The guiding devices are used to guide their users to reach the exact position of TD on site.

[0021] In yet another aspect of this invention, the method utilizes a system that is composed of also one or a plurality of wireless transmitters that have similar radio properties

as the TD, and are referred to as Reference Wireless Transmitting Devices or Reference Transmitter, or RT for short, also carried by the searching personnel(s). The MDS (and DS) measures not only the location of the TD, but also the location of the RT, and provides information about the relative location of the RT with respect to the TD. The method thereby involves making use of the advantages that are made available by the likeness of the radio properties of the TD and RT, by the measurement of the relative (and asymptotically identical) locations of the TD and RT, and by the real time feedback to the search movements. The method also enables a searching robot that is equipped with a RT to work with a MDS accomplishing the searching job.

[0022] In still yet another aspect of the invention, the RT and the guiding device are physically combined, and herein referred to as a Guiding and Reference Device, or GRD for short.

[0023] Other aspects of the invention will become clear thereafter in the detailed description of the preferred embodiments and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] Fig. 1 illustrates the location determination system and the method associated with thereof, in the on-vehicle operation mode, using a cellular phone as an example of target device;

[0025] Fig. 2 is an illustration of blockage of line of sight (LOS) and multipath propagation effects in a fictitious urban area that apply to a Movable Detection Station (MDS);

[0026] Fig. 3 is an illustration of a method of determining whether or not an individually detected earliest arrival propagation path is truly LOS or truly earliest arrival propagation path, in a fictitious multipath scattering environment that applies to a MDS;

[0027] Fig. 4 illustrates the location determination system and the method associated with thereof, in the off-vehicle operation mode, using a cellular phone as an example of target device;

[0028] Fig. 5 is an exemplary illustration of preferred display on screen for absolute and relative locations of TD, GRD(s) and MDS(s) in two dimensions, overlaid with local area map and remote sensing photo that are pre-stored on system;

[0029] Fig. 6 illustrates an alternative embodiment of the location determination system in which the MDS is equipped with an on-MDS BS transmitter, and the method associated with thereof, in the on-vehicle and off-vehicle operation modes, using a cellular phone as an example of target device;

[0030] Fig. 7 illustrates the location determination system and the method associated with thereof, in a three-dimensional operation mode, using a cellular phone as an example of target device;

[0031] Fig. 8 is a block diagram of the MDS in accordance with the preferred embodiments of the current invention;

[0032] Fig. 9 is a block diagram of the GRD in accordance with the preferred embodiments of the current invention.

[0033] The same reference numerals are used in different Figs. to denote similar elements.

DETAILED DESCRIPTION OF THE INVENTION

[0034] In the description hereafter, a cellular phone is used as an example of the Target Device (TD) for convenience of description. It is understood that the method and system described herein do not limit its TD to a cellular phone. Depending on the functionality provided by the TD, the TD may be a cellular phone, a PCS (Personal Communication Systems) phone, a satellite phone, a cordless phone, a two-way pager, a wireless PDA (Personal Digital Assistant), a wireless laptop computer, a data messaging device, a cellular telephone with data messaging capabilities, a wireless Internet appliance, a data communication device (with or without telephony capabilities), or a radio tag, and so on.

[0035] Also in the description hereafter, E911 service is used as an example application for convenience of description. It is understood that the method and system described herein do not limit its application to E911 service.

[0036] Fig. 1 illustrates the location determination system and the method associated with thereof, in the on-vehicle operation mode, using a cellular phone as an example of TD. Referring to Fig. 1, the TD **10** is a wireless transmitting device whose location is to be determined and searched. The particular TD shown in the figure is a cellular phone that is communicating with a Base Station (BS) **20A** through radio link **40A**, and in some circumstances (e.g., for a CDMA TD in a soft handoff) also communicating with additional BSs simultaneously, such as with BS **20B** via radio link **40B** shown also in the figure. The TD **10** is transmitting wireless signals, for example, in verbal communication with an operator at a Public Safety Answering Point (PSAP, not shown in the figure) after dialing the

emergency number "911" adopted in the North America, or staying on the line quietly after dialing "911", or being called back by an emergency response officer after hanging up his/her "911" call, or being initiated a wireless transmitting session in a Service Option that is specifically designed for location service, e.g., transmitting a pilot signal. Upon receipt of the "911" call, the PSAP operator would obtain the caller's rough location by means of verbal conversation, and/or by prior art "Phase I" E911 information that is automatically reported to PSAP by the wireless network in terms of serving BS **20A** location, and the round trip delay that may also be available, and/or by prior art "Phase II" E911 information that is reported to PSAP in terms of longitude and latitude of TD **10**, whose corresponding location is denoted in the figure as **60,** that is subject to errors statistically. Emergency response vehicles equipped with Movable Detection Station (MDS) **30A**, **30B** such as police cars, ambulances, and/or fire trucks are dispatched by PSAP to said rough location. Those skilled in the art understand that the parameters or properties of the transmitted signal by the TD **10**, such as the transmitting frequency of the TD, the transmitting slot position of the TD when the TD is operating in TDMA (Time Division Multiple Access) mode, the spreading code information of the TD when the TD is operating in CDMA (Code Division Multiple Access) mode or DSSS (Direct Sequence Spread Spectrum) mode, the frequency hoping information when the TD is operating in frequency hopping mode, phone number, and/or electrical serial number (ESN), can be made available to the MDS **30A**, **30B** from a database installed within or connected to the PSAP, from the wireless network which is connected to the PSAP, and/or from the air interface of the wireless communication system. Using said parameters or properties, the receivers of MDS **30A**, **30B** would attempt to acquire and receive the transmitted signal **50A**, **50B** from the TD **10**, while driving en route to the target location. As

shown in the figure, along the route the MDS **30A** would take a plurality of measurements of the incoming signal **50A'**, **50A** while moving from position **30A'** to position **30A**, and when taking each of the measurements, the position and orientation of MDS **30A** can also be determined using such means as GPS receiver installed on MDS **30A**. The plurality of measurements on parameters of the incoming signal **50A'**, **50A** that are performed at different time instants and different positions **30A, 30A'**, etc., along the route, together with the corresponding positions and orientations of MDS **30A** that are determined can be transformed into appropriate location estimation methods that are originally proposed for multiple fixed detection stations that take measurements at same time instants. Along the route, the MDS **30A** would continuously take new measurements and continuously refine the estimation of the TD **10** location. Those skilled in the art understand that, in the prior art network based solutions the number of available DSs (usually co-located at the BSs) that "hear" the signal from TD **10** are often found too few, especially in suburban and rural areas; the location geometry of available DSs in prior art that "hear" the signal from TD **10** with respect to the location of TD is often found disadvantageous to the accuracy of the location measurement; the blockage to the line of sight (LOS) propagation path and the multipth propagation effects in urban and suburban areas often cause the DSs at the fixed locations in the prior art network based solutions to produce unacceptable location measurement errors. By using MDS the number of measurements that can be obtained along the route of a MDS movement can be hundreds if not thousands; among them, measurements taken at disadvantageous positions can be excluded or weighted low. The disadvantageous measurements include those having low signal to interference ratios or signal to noise ratios, those of which the LOS or earliest arrival paths are weak or lost; those do not exhibit

advantageous geometry with tentatively measured TD location. Said exclusion or weighting process is progressive, i.e., a relatively good measurement will be kept while no better ones are available so far, but once sufficient better measurements become available, those previously preserved relatively "good" ones become not-good-enough and are excluded or weighted lower, and such updating process continues. The detection of the signal to interference ratio or signal to noise ratio can be accomplished by a signal to interference ratio estimator or a signal to noise ratio estimator that is familiar to the skilled in the art; the detection of late arrival multipath propagation paths in an individual measurement for purpose of exclusion in the location calculation can be implemented by a channel impulse response estimator that is familiar to the skilled in the art; disadvantageous geometry with tentatively measured TD location can be measured by geometrical dilution of position (GDOP), which is also well known to the skilled in the art and does not need further explanation. A method that determines whether or not an individually detected earliest arrival propagation path is truly LOS or truly earliest arrival propagation path will be further described subsequently with reference to Fig. 3. The mobility of the MDS can actually correct the measured errors that are caused by blockage of LOS and the multipath propagation through its ray tracing process. This is further explained next by referring to Fig. 2.

[0037] Fig. 2 is an illustration of blockage of line of sight (LOS) and multipath propagation effects in a fictitious urban area that apply to a MDS. Referring now to Fig. 2, the MDS **30** is moving on a street from position **30A'** towards **30A**. While at position **30A'**, the LOS **50A'''** from TD **10** is blocked by building **B**, but the MDS **30** receives the signal

50A' from TD **10** that is reflected by building **D**. The MDS **30** might think the TD is towards the direction of building **D** and thereby guides the vehicle of MDS **30** driving towards building **D**. Upon arriving at position **30A** in front of building **D**, the MDS **30** would have obtained similar visibility of building **D**, and MDS **30** thereby begins to see the LOS ray **50A**. Although MDS **30** also sees the reflected path **50A"**, MDS **30** would "realize" that ray **50A** is stronger and arrives earlier, and is a more preferable signal to trace. This guides the MDS **30** driving towards building **C** where TD **10** is truly located. It can be realized that, without a MDS **30** equipped on board of the emergency response vehicle, a fixed DS co-located at a BS (not shown in the figure) that sees earliest arrival path reflected from building **D** would have guided the emergency response crew to building **D** by mistake, and risking the life of the emergency caller.

[0038] Fig. 3 is an illustration of a method of determining whether or not an individually detected earliest arrival propagation path is truly LOS or truly earliest arrival propagation path, in a fictitious multipath scattering environment that applies to a MDS. Referring now to Fig. 3. A MDS **30** moves along the road and takes measurement on the signals transmitted by TD **10** at positions **30A, 30A'** and **30A"**. Buildings **A, B, C,** and **D** in the surrounding area form blockage and/or reflection land structures to the signal propagations from TD **10** to MDS **30**. At position **30A**, the MDS **30** detects a propagation path **50A$_1$** reflected from building **C**, but the LOS propagation path **50A$_2$** is too weak to be detected due to blockage by building **A**. Therefore, although arriving later than **50A$_2$**, **50A$_1$** is the detected earliest arrival propagation path at position **30A**. When the MDS **30** arrives at position **30A'**, the LOS propagation path **50A'$_3$** is still too weak to be detected due to blockage by building **A**,

however MDS **30** can detect propagation path **50A'$_1$** and **50A'$_2$** reflected from building **C** and **B**, respectively. Between **50A'$_1$** and **50A'$_2$**, the MDS **30** can determine that **50A'$_2$** arrives earlier than **50A'$_1$** through its means to distinguish multipaths. Therefore, **50A'$_1$** is determined NOT to be earliest arrival propagation path, while **50A'$_2$** is the individually detected earliest arrival propagation path at position **30A'**. Whether or not the **50A'$_2$** is truly earliest arrival propagation path is still undetermined solely based on measurement taken at position **30A'**. Now, based on the measurements taken at two positions, **30A** and **30A'**, we try to determine jointly whether the individually detected earliest arrival propagation paths, **50A$_1$** and **50A'$_2$** are truly LOS propagation path or truly earliest arrival path. The method is to measure the difference of the propagation delays of the individually detected earliest arrival propagation paths from TD **10** to MDS **30** at the two positions, **30A** and **30A'**, and also determine the distance between the two positions **30A** and **30A'**; if the delay difference is larger than the distance divided by the speed of light, then, between the two paths, the longer delay path is determined NOT truly LOS propagation path, or NOT truly earliest arrival propagation path; if the delay difference is not larger than the distance divided by the speed of light, then both paths are still UNCERTAIN whether they are truly LOS propagation paths or truly earliest arrival propagation paths. In this example, if the delay from TD **10** to building **C** and then to **30A** is longer than that from TD **10** to building **B** and then to **30A'** by an amount of distance between **30A** and **30A'** divided by the speed of light, then the individually detected earliest arrival propagation path **50A$_1$** is NOT truly LOS propagation path or NOT truly earliest arrival propagation path; if the said former delay is shorter than said latter delay by the same said amount, then the individually detected earliest arrival propagation path **50A'$_2$** is NOT truly LOS propagation path or NOT truly earliest

arrival propagation path; otherwise, both individually detected earliest arrival propagation paths **$50A_1$** and **$50A'_2$** are still UNCERTAIN whether they are truly LOS propagation path or truly earliest arrival propagation path, solely based on measurements taken at positions **30A** and **30A'**. When the MDS **30** arrives at position **30A"**, we see in Fig. 3 that MDS **30** observes the LOS propagation path **50A"**, however MDS **30** itself does not know about this fact and it still needs to use said individual and said joint method to determine it. In the joint determination method, MDS **30** will measure the delay difference of paths **50A"** and **$50A'_2$**, and determine the distance between **30A"** and **30A'**, use said rules to find out whether any of the paths **50A"** and **$50A'_2$** can be determined as NOT truly LOS propagation path or NOT truly earliest arrival propagation path. If the paths **50A"** and **$50A_1$** still remain UNCERTAIN whether they are truly LOS propagation path or truly earliest arrival propagation path, the method can also be further applied to the pair of measurements obtained at positions **30A"** and **30A**, using the corresponding delay difference and distance between positions **30A"** and **30A**. While MDS **30** continues to drive further, the method can be further used between any pair of measurements taken along the route where the associated individually detected earliest arrival propagation path remains UNCERTAIN whether it is truly LOS propagation path or truly earliest arrival path.

[0039] Now referring back to Fig. 1, in an alternative embodiment, a plurality of MDSs, hereby represented as **30A** and **30B,** will communicate through direct or indirect radio links (not shown in the figure) with each other, and pass their individually measured parameters regarding signals **50A,50B** from TD **10** to each other **30A,30B**. The measured parameters

obtained by the plurality of MDSs, **30A,30B** are combined in solving the location of TD **10**, resulting in higher accuracy and reliability.

[0040] Also referring to Fig. 1, in yet another alternative embodiment, one or a plurality of MDSs **30A,30B** will further communicate with fixed DS **70A,70B,** which may be co-located at BS **20A,20B,** through wireless and/or wired communication channels (not shown in the figure), and share their measured parameters regarding signals **40A,40B,50A,50B** from TD **10** with one anther **30A,30B,70A,70B**. The parameters measured by the MDSs **30A,30B** and by the fixed DSs **70A,70B** are combined at MDSs **30A,30B** and/or at DSs **70A,70B** in solving the location of TD **10**, resulting in further improved accuracy and reliability.

[0041] Fig. 4 illustrates the location determination system and the method associated with thereof, in the off-vehicle operation mode, using a cellular phone as an example of TD. Now referring to Fig. 4. After having determined the site (a localized small area or land structure) where TD **10** is located, either using method and system described above, or using alternative methods and systems, or a combination thereof, the MDS equipped vehicle **30A** parks at a close location on site. The members of the emergency response team equipped with Guiding and Reference Devices (GRD) **100A,100B** walk off the vehicle **30A** to approach the exact location of TD **10**. A reference transmitter (RT, to be further explained in the description of Fig. 9 subsequently) within the GRD **100A,100B** will set up a call via radio link **110A,110B** with the same BS **20A** that TD **10** is communicating with. The call on **100A,100B** via radio link **110A,110B** is in the same operating mode as that of TD **10**'s call over radio link **40A**, e.g., if TD **10** is calling in CDMA mode, then **100A,100B** also calls in CDMA mode, if TD **10** is calling in GSM mode, then **100A,100B** also calls in GSM mode,

etc.. The call of GRD **100A,100B** over the radio link **110A,110B** is preferred to be at the same frequency as that of TD **10** over **40A**, if possible (e.g., occupying another time slot at the same frequency channel in a TDMA based call, occupying another spreading code at the same frequency channel in a CDMA based call), and when this is impossible (e.g., a call based on FDMA), a channel with as close frequency to the one on radio link **40A** as possible is preferred. The same or close frequency, or more generally, the likeness of the radio properties of the associated signals would make the propagation properties for the radio links of TD **10** and GRD **100A,100B** similar and asymptotically identical when the GRD **100A,100B** approaches the TD **10**. The radio signals transmitted from GRD **100A,100B** are also being received by the MDS **30A,30B** via radio links **120A,120B,120C,120D**, and thereby the locations of GRDs **100A,100B** are measured by MDS **30A,30B** simultaneously while the location of TD **10** is being measured. Although the location measurement accuracy for the TD **10** and that for the GRD **100A,100B** each could be individually degraded by blockage of LOS and by multipath propagation, because of the fact that TD **10** and GRD **100A,100B** would experience similar and asymptotically identical multipath effects when GRD **100A,100B** approaches TD **10**, the relative location between TD **10** and GRD **100A,100B** measured by the MDS **30A,30B** would have been affected very little and thereby is more reliable than the absolute location measurement. In order for the MDS **30A,30B** to have similar detectability on signals transmitted by TD **10** and GRD **100A,100B**, other signal properties of TD **10** and GRD **100A,100B**, such as transmitted power and durations are also preferably made similar to each other. In some occasions, although the emergency response personnel(s) holding the GRD **100A,100B** is very close in distance to the TD **10**, they might be within difference construction structures such as two different stairs separated by a wall

and cannot reach each other. Adding a detection means for the likelihood of such occasions will increase the efficiency of the search. Such detection can be achieved by comparing the likeness of the signal characteristics transmitted by TD **10** and GRD **100A,100B**, such as comparing the difference in received signal strengths or reported transmitted power levels of the signals from TD **10** and GRD **100A,100B**, and/or comparing the likeness of the multipath propagation profiles thereof. The guiding to the search for TD **10** described herein also applies to a method using a searching robot, wherein a robot replaces the search personnel in function, a RT and a compass sensor installed on the robot replaces the GRD **100A,100B** functionality in one part (the functionality of the compass sensor will be described subsequently in reference to Fig. 9), and a display device installed on a robot control station replaces the GRD **100A,100B** functionality in another part. Other aspects remain the same.

[0042] Also referring to Fig. 4, the MDS **30A** and GRD **100A,100B** also include another set of radio transceivers, preferably Wireless Local Area Network (WLAN) transceivers, to communicate with each other via radio link **120A',120C'**. Through radio link **120A',120C'**, information for display on the screen of GRD **100A,100B** is conveyed, to display the TD **10** location relative to those of the GRD **100A,100B**, optionally also to those of the MDS **30A,30B,** and to guide the users of GRD **100A,100B** movement by movement in the search for TD **10**. An example of the preferred two dimensional display on screen of GRD **100A,100B** and on screen of MDS **30A,30B** for absolute and relative locations of the TD **10**, GRD **100A,100B** and MDS **30A,30B** is shown in Fig. 5.

[0043] Now referring to Fig. 5. Fig. 5 is an exemplary illustration of preferred display on screen for absolute and relative locations of TD, GRD(s) and MDS(s) in two dimensions.

Preferably the display is in color (not being able to shown on Fig. 5 due to document format limitation), the symbols that mark the measured locations of TD **10**, GRD **100A,100B** and MDS **30A,30B** are overlaid with local area map, and preferably further overlaid with pre-stored remote sensing photo that shows the land structures.

[0044] Fig. 6 illustrates an alternative embodiment of the location determination system in which the MDS **30A,30B** are equipped with an on-MDS BS transmitter, and the method associated with thereof, in the on-vehicle and the off-vehicle operation modes, using a cellular phone as an example of target device. Now referring to Fig. 6, in the same way as in the description of Fig. 1, after TD **10** calls 911, the PSAP (not shown in the figure) dispatches the emergency response vehicles that are equipped with MDS **30A,30B** to the rough location according to the information obtained by the said PSAP; the TD **10** is transmitting signals to communicate with its serving BS **20A** via radio link **40A** and in some cases simultaneously with additional BSs, such as BS **20B** via the radio link **40B**; when the MDS **30A,30B** are close enough to the location of TD **10**, the MDS **30A,30B** can detect the signal being transmitted by TD **10** via radio link **50** and the up link direction of radio link **200** (the direction from TD **10** to MDS **30A**) and can start to measure and refine the location of TD **10**. At a point when the radio link between TD **10** and one of the dispatched emergency response vehicles, say the link **200** between TD **10** and MDS **30A**, becomes of better quality than that of link **40A** (and if available, **40B**), the corresponding MDS **30A** would enable its on-MDS BS transmitter within MDS **30A**, and informs the serving BS **20A** to send handoff/handover command to TD **10**. The said handoff/handover command asks TD **10** to handoff/handover to MDS **30A**. Receiving and executing said handoff/handover command,

the TD **10** then establishes two-way communication with MDS **30A** via radio link **200**, and disconnects the radio link(s) **40A** (and **40B** if available). Because of the close-in distance between TD **10** and MDS **30A** and thus the better quality of radio link **200**, the communication between the TD **10** and the emergency response team would be more reliable, and in addition, the power control instructions transmitted by the on-MDS BS transmitter within MDS **30A** that are available in many wireless standards would result in lower average transmitted power at TD **10** due to the close-in distance to MDS **30A** and better quality of radio link **200**, and thereby increase the talk time of battery on TD **10** that may be necessary for the continuation of the location detection in progress. Said power control instructions transmitted by the on-MDS BS transmitter within MDS **30A** can further take the advantage of being able to coordinate with the MDS **30A** measurement activity to further increase the talk time of TD **10**, and optimize the signal to interference ratio for better location measurement accuracy. Additional signal properties can also be controlled in coordination with the MDS **30A** measurement activities for improved accuracy and battery life. In the same way as in the description of Fig. 4, after having determined the site where TD **10** is located, the MDS equipped vehicle **30A** parks at a close location on site; the members of the emergency response team equipped with GRD **100A,100B** walk off the vehicle **30A** to approach the exact position of TD **10**. Unlike in Fig. 4, the reference transmitter (to be further explained in the description of Fig. 9) within the GRD **100A,100B** will set up a call via radio link **210A,210B** with MDS **30A** instead of BS **20A**. The call properties on **100A,100B** via radio link **210A,210B** are otherwise the same as in Fig. 4, e.g., in the same operating mode as that of TD **10**'s call over radio link **200**, preferred to be at the same frequency as that of TD **10** over **200**, if possible, and when this is impossible (e.g., a

call based on FDMA), a channel with as close frequency to the one on radio link **200** as possible is preferred. The way to utilize GRD **100A,100B** to search for the exact position of TD **10** is also the same as in the description of Fig. 4. The down link of **210A,210B** (from on-MDS BS transmitter within MDS **30A** to the receiver associated with the reference transmitter within GRD **100A,100B**) is preferred to perform a new task, to convey the data for display on the screens of GRD **100A,100B**, in addition to the possible voice communication between the TD caller and the emergency response officer, eliminating the need for the WLAN transceivers on both MDS **30A,30B** and GRD **100A,100B**. Further, the power control instructions transmitted by the on-MDS BS transmitter within MDS **30A** to the GRD **100A,100B** can take the advantage of being able to coordinate with the MDS **30A** measurement activity to optimize the signal to interference ratio for better location measurement accuracy of GRD **100A,100B,** and increase the battery life of GRD **100A,100B** as well. The frequency and other signal properties of the on-MDS BS transmitter should be chosen appropriately to minimize the impact to the wireless system operation of BS **20A,20B** and their serving users.

[0045] Fig. 7 illustrates the location determination system and the method associated with thereof, in a three-dimensional operation mode, using a cellular phone as an example of TD. Referring to Fig. 7, in a preferred embodiment, when at least one of MDS **30** is sufficiently close to TD **10**, or after at least one of the MDS **30** is parked on site, the location measurement is conducted in three dimensions, so that the height of TD **10** and height of GRD **100** would not be a degradation factor in determining location in horizontal plane, and further, said height of TD **10** and height of GRD **100** are also measured and reported on

screen of GRD **100** and on screen of MDS **30** to provide additional location information. The format of the display for height is preferably a number marked beside each symbol on a two-dimensional graph, or popped-up beside each symbol upon being commanded by user, the value of the height is preferably being displayed in relative to that of the MDS **30**. Alternatively the display for height is in three-dimensional graphical effects.

[0046] In the descriptions thereinbefore, the number of the MDS **30** and the number of GRD **100** are exemplary. In the implementation and application of this invention, the number of MDS **30** can be one or plurality, the number of GRD **100** can also be one or plurality. The number of MDS **30** and the number of GRD **100** are not necessarily equal.

[0047] Fig. 8 is a block diagram of the MDS in accordance with the preferred embodiments of the current invention. Referring to Fig. 8, the preferred embodiment of MDS **30** is composed of an antenna **305**, a receiver **310**, a GPS antenna **315**, a GPS receiver **320**, a digital signal processing (DSP) subsystem **325**, a calibration antenna **330**, a calibration transmitter and mobile receiver **335**, a display and user interface **345**, a WLAN antenna **350**, a WLAN transceiver **355**, a gravity sensor **360** and a compass sensor **365**. Optionally, the MDS **30** further includes an on-MDS BS transmitter **370** and a transmitting antenna **375**.

[0048] The antenna **305** is used to receive the signals from the TD **10**, and from GRD **100,100A,100B** for measurement of their locations. The antenna **305** is preferred to be an array antenna so as to enable AOA (angle of arrival) measurement of the signals from TD **10** and GRD **100,100A,100B,** in addition to such measurements as TOA (time of arrival) and/or TDOA (time difference of arrival) and their variations, as well as other alternative signal

parameter measurements. Furthermore, the antenna **305** is preferred to be a three-dimensional array antenna, i.e., the elements of the arrays span in three dimensions, to enable AOA measurement in three dimensions. The antenna **305** is also preferred to be installed on top of the roof of a land vehicle or a water boat, or be installed under lower deck of a helicopter or other types of over-the-air moving platform, to achieve good visibility over a wide range of angles for incoming signals from land structures.

[0049] The receiver **310** converts the RF (radio frequency) signals received by antenna **305** to baseband and digitizes the signals. The functionality of the receiver **310** is familiar to those skilled in the art, such as amplifying, down conversion, filtering, automatic gain control, analog to digital conversion, etc., and thereby does not need to elaborate further. For AOA measurement, preferably the receiver **310** is an array receiver that is composed by a plurality of identical channels whose down-conversion stages utilize a common or synchronized frequency source. Preferably said common frequency source is provided by the GPS receiver **320**. The digitized baseband output of the receiver **310** is provided to the DSP subsystem **325** for further processing as will be further detailed thereafter.

[0050] In an alternative embodiment, the antenna **305** is a narrow beam antenna being installed on a rotating structure with an angle sensor, for measurement of AOA. Said rotating structure is preferably being able to rotate in three dimensions for AOA measurement in three dimensions.

[0051] The GPS antenna **315** receives signals from the GPS (Global Positioning System) satellites or from other satellites that perform the similar functionality, such as GLONASS (Global Navigation Satellite System), BEIDOU, or GALILEO in proposal, although still being referred to herein as GPS antenna. The antenna is preferably being installed on top roof

of the moving platform to achieve good visibility of the satellites in sky. The signals received are provided to the GPS receiver **320**.

[0052] The GPS receiver **320** receives signals from GPS satellites provided by the GPS antenna **315**, or receive signals from other types of satellites providing the similar functionality such as GLONASS, BEIDOU or GALILEO, although still being referred to herein as GPS receiver. The GPS receiver **320** by receiving and processing the received signals from said satellites produces following output to the rest of the MDS **30**: the accurate frequency and time reference source; the location of the MDS **30,30A,30B** in terms of longitude, latitude and height as well as the moving direction of the MDS **30,30A,30B**, or signals related to thereof.

[0053] The antenna **330** is a radio emitting element that is used for calibrating the array antenna **305** and the array receiver **310**. The antenna **330** is built with fixed and known propagation delays to each element of the array antenna **305**, and preferably is built within the same solid structure of the array antenna **305** to ensure a predetermined delay of the radio link **340** between calibration antenna **330** and each element of the array antenna **305**. The calibration signal fed to the calibration antenna is provided by the calibration transmitter **335** to be described next. The antenna **330** also receives signals from the serving basestation(s) **20A,20B** of TD **10**.

[0054] The calibration transmitter part of the calibration transmitter and mobile receiver **335** produces a signal for calibrating the array antenna **305** and the array receiver **310**. Preferably it can be programmed to produce the signal with same frequency and the same modulation formats that the TD **10** and the GRD **100,100A,100B** would transmit, so that the calibration can be conducted at the exactly same working condition as the MDS **30**'s location

measurement operation would be on. Upon receipt of the TD **10** parameters (e.g., frequency and modulation mode), and before starting the location measurement, the MDS **30** will preferably conduct the calibration. The mobile receiver part of the calibration transmitter and mobile receiver **335** receives signals from serving basestation(s) **20A,20B** of TD **10** to obtain signaling messages and network timing.

[0055] The display and user interface unit **345** includes a screen to accept data from the DSP subsystems **325** to display the local map with overlaid symbols of TD **10** location, GRD **100,100A,100B** location and the MDS **30,30A,30B** location. Preferably the display also shows the stored remote sensing photo of local land structures, being overlaid on the local map. An example has been given in Fig. 5. The unit **345** also accepts user control to the MDS **30**.

[0056] The WLAN transceiver **355** and the antenna **350** transmits the images or image parameters produced by DSP subsystem **325** to the GRD **100,100A,100B** via radio link, for display on screen of GRD **100,100A,100B**. Although the unit **355** is referred to herein as a WLAN transceiver and is preferred to utilize a WLAN transceiver, it does not exclude the use of other types of transceivers in implementing the invention.

[0057] The gravity sensor **360** reports information about the vehicle tilt to DSP subsystems **325** for use to correct the AOA measurement computation in DSP subsystems **325.**

[0058] The compass sensor **365** reports the vehicle orientation to DSP subsystems **325** while vehicle is parked, for use to correct the AOA measurement computation in DSP subsystems **325.** For the magnetic compass sensors, the sensor is preferably being calibrated

by the direction computed by movement based on GPS while moving, to eliminate the magnetic interference of the vehicle structure.

[0059] Alternatively, the gravity sensor **360** and compass sensor **365** can be combined into a gyroscope based sensor and/or acceleration sensor.

[0060] The DSP subsystem **325** includes signal processing devices such as ASIC (application specific integrated circuits), FPGA (field programmable gate array), DSP processor(s), micro controller(s), and/or general purpose microprocessor(s), memory devices, mass storage devices and peripheral devices. The functionality of DSP subsystem **325** in MDS **30** includes: conducting calibration of the array receiver; computing the AOA, TOA, TDOA and/or other alternative or related parameters of the incoming signals from TD **10** and GRD **100,100A,100B**; computing the longitude, latitude and height of the TD **10**, GRD **100,100A,100B** and MDS **30**; while moving, computing the direction of moving of the MDS **30** based on position changes of the MDS **30** reported by the GPS receiver **320**; while staying stationary, finding the vehicle orientation based on input from the compass sensor **365**; finding the vehicle tilt based on input from the gravity sensor **360**; overlaying the positions of MDS **30** (provided by GPS receiver **320** or computed by DSP subsystem **325**), the TD **10**, and the GRD **100,100A,100B** onto a local area map electronically stored in the mass storage device, rotating the overlaid image based on the vehicle moving direction or parking orientation, responding the user's command from user interface **345** to zoom, move, or attribute change to the image, and producing the final image for display; outputting said image to the display and user interface unit **345**; outputting the image or image parameters to the WLAN transceiver **355** to transmit to the GRD **100,100A,100B** for display on the GRD screen(s); controlling and configuring all functional parts within MDS **30**. When the on-MDS

BS transmitter **370** and its associated antenna **375** (to be described in the next paragraph) is equipped within MDS **30**, the DSP subsystem **325** (together with receiver **310**) further performs all additional functionalities that a BS receiver will perform, e.g., decoding of the in coming signals from TD **10** that are passed to DSP subsystem **325** by receiver **310**.

[0061] In an alternative embodiment, the MDS **30** further includes an on-MDS BS transmitter **370**, and its associated antenna **375**. The on-MDS BS transmitter **370** would perform the functionalities of a regular base station transmitter which include performing the communication protocols, converting digital signals to analog, modulating, performing power control for the serving terminals TD **10** and GRD **100,100A,100B**, up-converting to radio frequency, amplifying the power, and radiating the signal through the antenna **375** to the air. In addition, as has been stated in the description of Fig. 6, the on-MDS BS transmitter **370** and antenna **375**, when in use, can perform the functionalities of the WLAN transceiver **355** and antenna **350** to convey the data for display on screen of the GRD **100,100A,100B**.

[0062] Fig. 9 is a block diagram of the GRD in accordance with the preferred embodiments of the current invention. Now referring to Fig. 9, the preferred embodiment of GRD **100** is composed of a reference transmitter **440**, an antenna **450** for the reference transmitter, a WLAN transceiver **430**, an antenna **460** for the WLAN transceiver, a microprocessor **410**, and a display and user interface unit **420**. In alternative embodiments as will be further detailed later, the GRD **100** further includes a GPS receiver **480** and an antenna **490** for the GPS receiver, and a compass sensor **470**.

[0063] The reference transmitter **440** is a device that can transmit the signal at the same or a close frequency and in the same mode of modulation as the TD **10** according to the air

interface standard. Depending on the standard in use, usually the transmitter is also required to work with a receiver for such functions as power control, and processing according to protocols defined in the standard. Thereby, in such circumstances the reference transmitter **440** in essence is a mobile station, which includes an associated receiver although not explicitly marked in the figure, and said transmitter (and associated receiver) **440** preferably supports multiple bands and multiple standards. For example, it can also support regular voice communication with any telephone, including calling the TD **10**. As has been described earlier, the main functionality of the reference transmitter is to transmit the signal that is measured by MDS **30,30A,30B** for determining its location relative to that of the TD **10**.

[0064] The WLAN transceiver **430** communicates with its counterpart WLAN transceiver **355** in MDS **30** (Fig. 8), to receive the data for display on the display and user interface unit **420** of the GRD **100**. Although the unit **430** is referred to herein as a WLAN transceiver and is preferred to utilize a WLAN transceiver, it does not exclude the use of other types of transceivers in implementing the invention.

[0065] The microprocessor **410** controls and configures all the functional units in the GRD **100**. It also accepts user commands from display and user interface unit **420** to control the GRD **100**, including to control the display on the screen, such as zoom, move, change attributes and formats of the image.

[0066] In an alternative embodiment, the compass sensor **470** reports the orientation of the handheld unit of GRD **100** to the microprocessor **410**, and the microprocessor **410** will rotate the image being displayed on screen of display and user interface unit **420** so that the displayed image orientation is always identical to the actual orientation of the GRD **100**

body, for convenience of the user to search for the TD **10** in the same direction as shown on screen in relative to the position of GRD **100**.

[0067] In yet another alternative embodiment, while GRD **100** is used in an area where GPS signals are of sufficiently good quality, the GPS receiver **480** and the GPS antenna **490** that are also included in the GRD **100** receive signals from GPS satellites and reports the location of GRD **100** to the microprocessor **410**. The reported position will be transmitted back to MDS **30** via the WLAN transceiver **430** and antenna **460**. Upon receipt of the location from GPS receiver **480** in GRD **100**, the MDS **30** will use said location information to correct the GRD locations measured by MDS **30** itself.

[0068] In still yet another alternative embodiment, as has been stated in the descriptions of Fig. 6 and Fig. 8, when the MDS **30** utilizes an on-MDS BS transmitter **370** and associated antenna **375**, the reference transmitter (and its associated receiver) **440** and antenna **450** can perform the functionalities of the WLAN transceiver **430** and antenna **460** to receive the data for display on screen of display and user interface unit **420**. The WLAN transceiver **430** and antenna **460** can be eliminated from GRD **100** in this embodiment.

[0069] The method and system described thereinbefore, while used in certain location applications other than E911, the wireless transmitting session of the TD **10** can be either TD originated or TD terminated, with or without human involvement. For example, it can be a call made by TD **10** after the TD **10** is triggered by certain means; it can be a call made by a person or by a machine that is terminated at the TD **10**; it also can be a specially defined transmitting session.

[0070] Throughout this specification, including the claims and drawings, the terminologies of a "reference transmitter (RT)" and a "reference wireless transmitting device" are used interchangeably. Furthermore, as has been stated, when an RT is combined with a "guiding device", the combined device that has RT and guiding device functionalities is referred to as a guiding and reference device (GRD). According to the context, when referring to a GRD, it may refer to the RT functionality or the guiding device functionality or both of the GRD; when referring to a guiding device, it may mean a standalone guiding device, or the guiding device functionality of a GRD; and when referring to an RT or a reference wireless transmitting device, it may mean a standalone RT or a standalone reference wireless transmitting device, or the RT functionality of a GRD.

[0071] The embodiments described herein are examples of structures, systems or methods having elements corresponding to elements of the invention. This written description may enable those skilled in the art to make and use embodiments having alternative elements that likewise correspond to the elements of the invention. The intended scope of the invention thus includes other structures, systems or methods that do not differ from the invention as described herein, and further includes other structures, systems or methods with insubstantial differences from the invention as described herein.